An Algorithm to Simulate Surface Creation without Element Deletion or Remeshing

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Outline

- Introduction
- Background on Fracture Modeling
- Algorithm
- Results
  - Comparison with standard simulation
  - Comparison with published results

Introduction

- Fracture modeling - perpetual research topic
  - 2 Requirements
    - Fracture criteria
    - Follow evolving geometry
  - Many good methods available
  - Validation and development continue
- Not generally available to analyst
  - Simple methods in commercial codes
  - Research and user written codes

Geometry Evolution

- Intra - Element
  - Evolution by element deformation
  - Advantage: Direct incorporation into FE model
  - Disadvantage: Discretization issues (distortion, size dependence, blunt crack, etc.)
- Exo - Element
  - Evolution by element separation
  - Advantage: Explicit model of surface
  - Disadvantage: Non-standard mesh/solution

Exo - Element

- Continuous Interface
  - Binary behavior - interface is either continuous or a free surface
  - Nodal release
    - Along a symmetry plane
    - Specific crack path within a mesh
    - Solution dependent crack path
  - Need method to selectively constrain nodes
  - Crack advance occurs in steps
  - Available in commercial codes

Exo - Element

- Interface Element
  - Small or zero thickness element at interface
    - Element either translates force (continuum/sliding) or doesn’t translate force (free surface)
  - Springs connecting nodes
  - Line / Surface elements
  - Available in commercial codes in theory
    - In practice - Difficult to use, discretization is non-standard, stability issues

Exo - Element

- Cohesive Zone
  - Traction - displacement relationship at interface
  - Idea stems from Dugdale - Barenblatt model of crack growth
  - This work is yielding results
    - Accurate reproduction of fracture details
  - Not generally available in commercial codes

Exo - Element

- Differences in models are slight
  - Distinction is often in name only
- Each method contains
  - Continuum model
  - Fracture process
  - Free surface
- Not difficult to recast the methods

Fracture Simulation

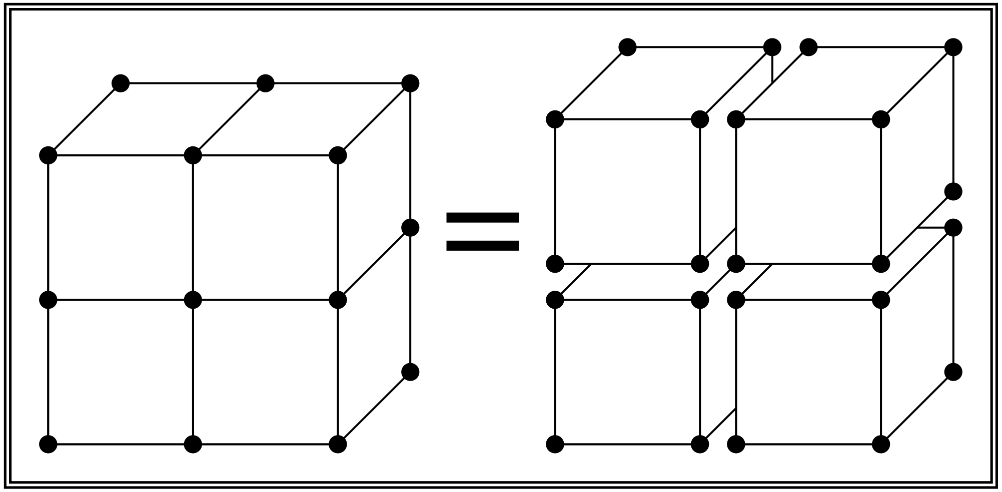
- Transition from research to general use seems imminent
  - Many 2-D examples of success
  - 3-D examples are limited
- Direction for general use is unclear
  - Methods require special discretization
    - Logistics of mesh handling are difficult
  - No clear choice for fracture criteria

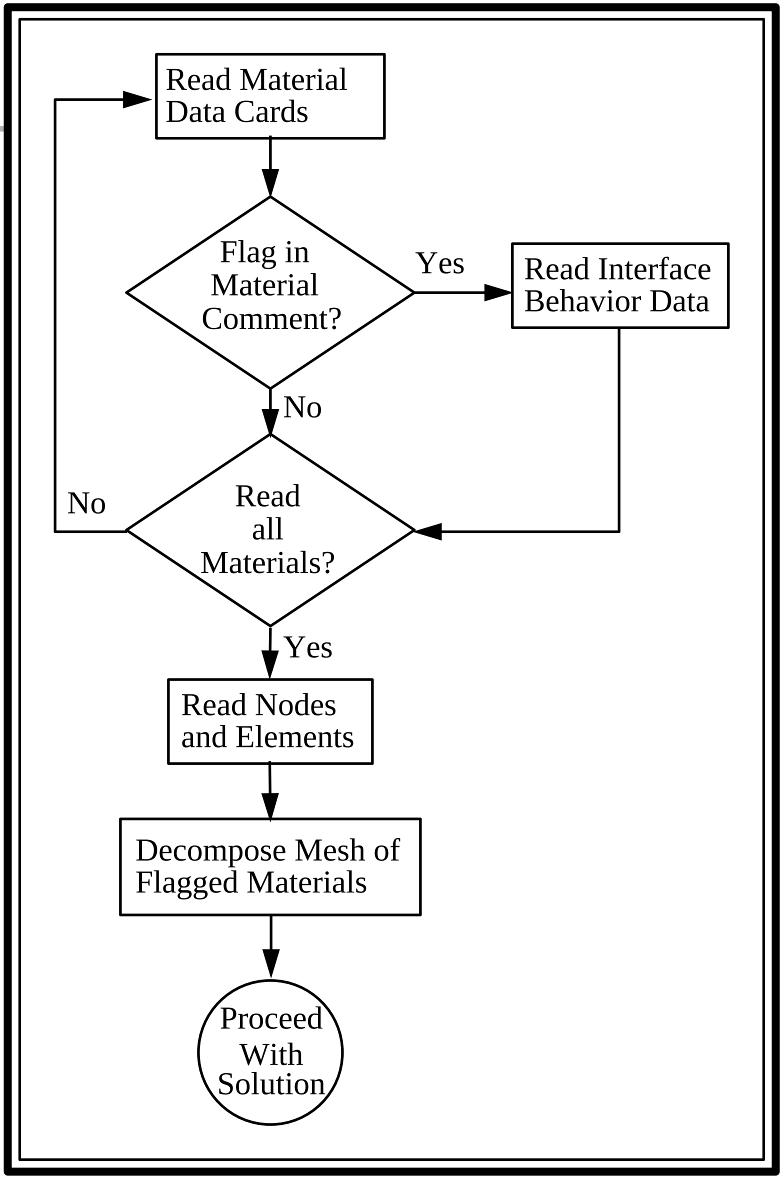
Algorithm

- Objective
  - Implement a method of geometry evolution that is easy to use in a developed FE code
  - Provide a means to validate fracture criteria
- DYNA3D - Explicit FE Code - LLNL
  - Exo-Element
  - Uses a standard mesh - internally modified
  - Maintain interface continuity
  - Evaluate fracture - separation
  - Evaluate contact of new geometry

Mesh Modification

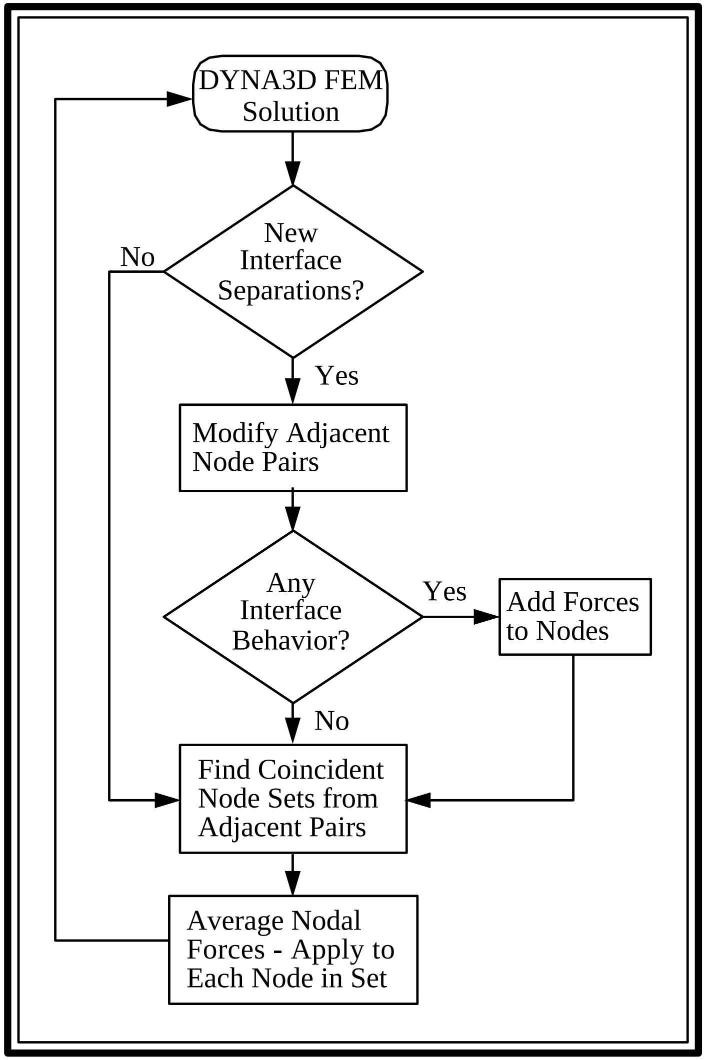
- Decompose Mesh
  - Add Nodes
  - Store Interface Data
  - Apply BC's





Fracture Process

- Evaluate Fracture
  - Function of local variables
    - Nodal - acc., vel., disp., etc.
    - Element - ε, σ, material parameters, etc.
    - Time
    - Interface state variables
- Discontinuous Interface
  - Traction - Nodal force added to FEM solution
  - No Traction - (Semi)Independent surface



Solution Modification

- Ensure Continuity

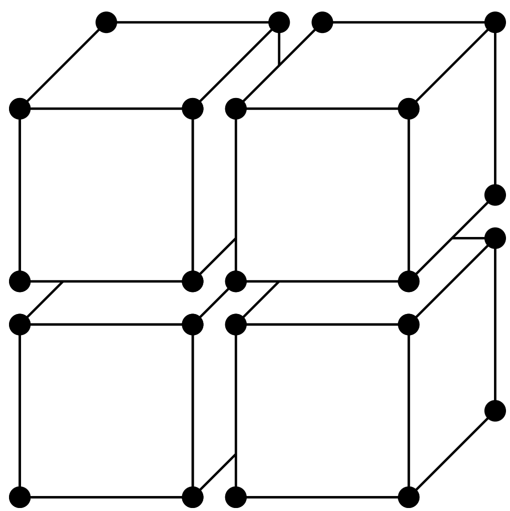
$$\vec{\bar{a}} = \vec{F} / M$$

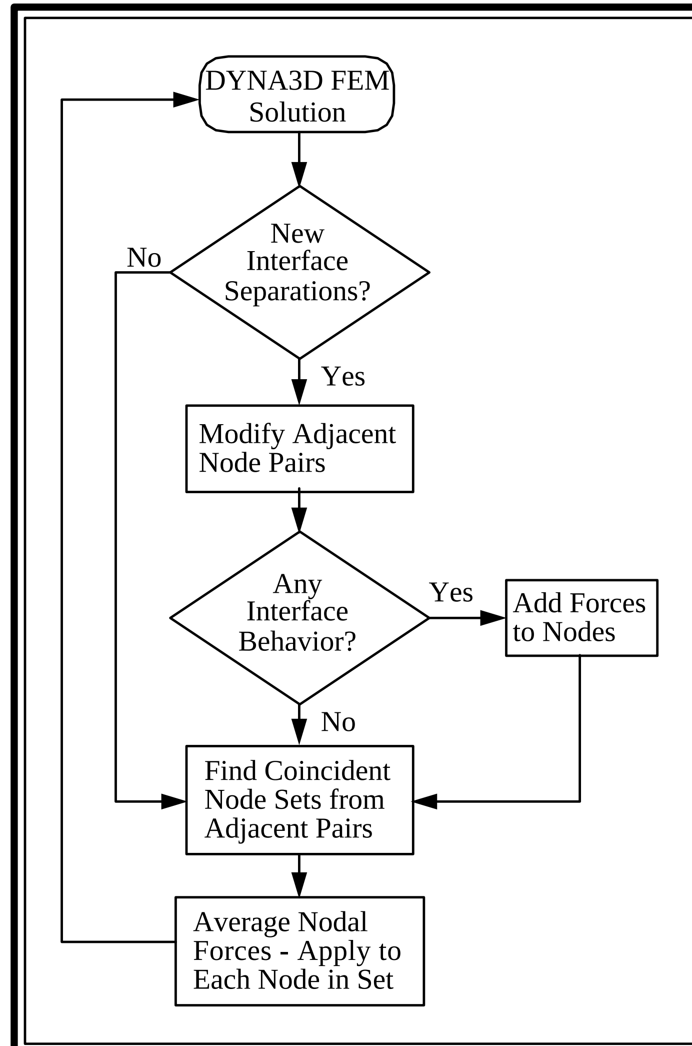
$$\vec{f}_i = \vec{\bar{a}} / m_i$$

where,

$$\vec{F} = \sum_i \vec{f}_i$$

$$M = \sum_i m_i$$





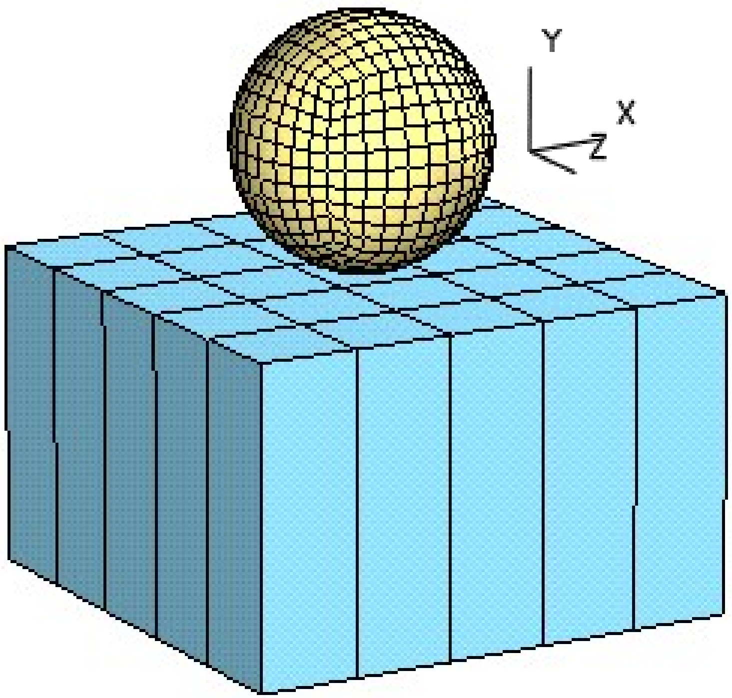
Contact

- Slidesurface with Adaptive New Definitions
  - Standard Use
    - All “external” faces are contact surface
    - Evolve contact surface as elements are deleted
  - For fracture algorithm
    - All element faces are “external”
    - Remove element interfaces from contact surface
    - Add them when the interface fails

Compare w/Standard Simulation

- Oblique Impact of Alumina Ball

$$\vec{V} = -75 \cdot \vec{e}_2 + 50 \cdot \vec{e}_3$$



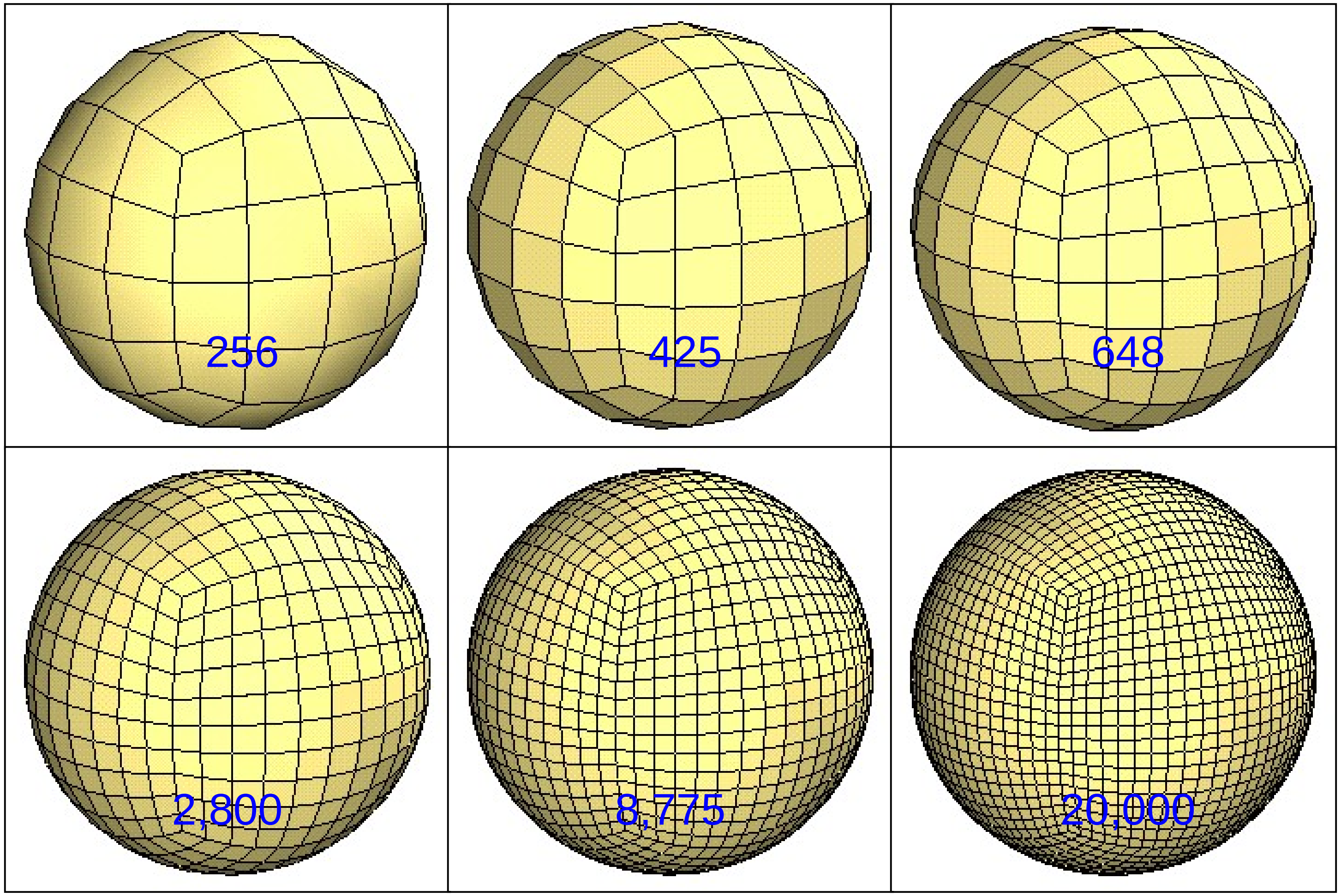
Young's Modulus	= 366 GPa
Density	= 3.96 g/cc
Poisson's Ratio	= 0.22
Tensile Strength	= 310 MPa

<u>Interface Failure Criterion:</u>

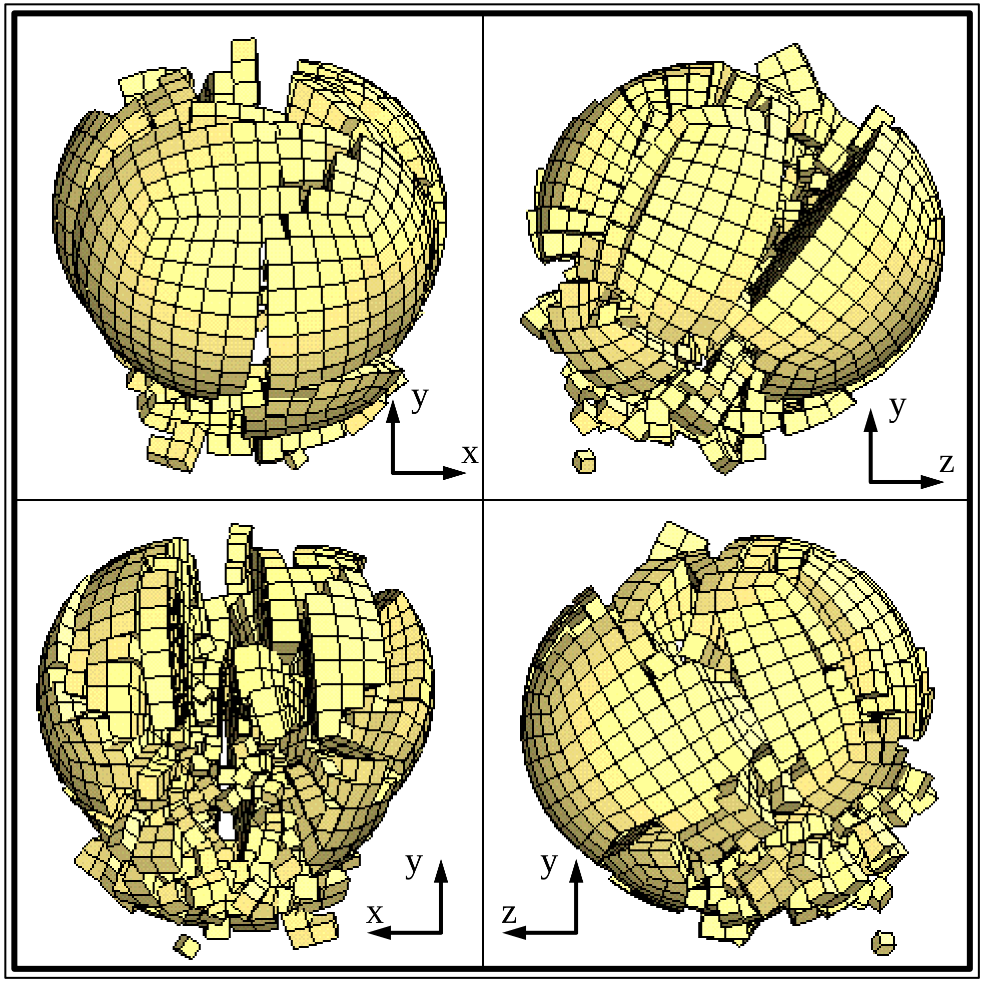
$$\bar{\sigma} = \frac{\sigma_1{}^n + \sigma_2{}^n}{2}$$

$$\bar{\sigma} > \sigma_{TS}$$

Comparison



Comparison

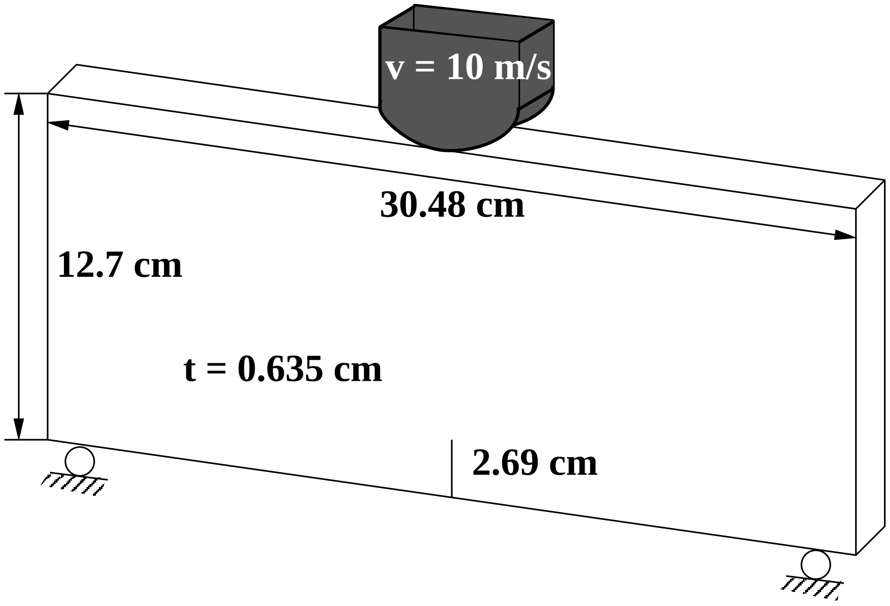


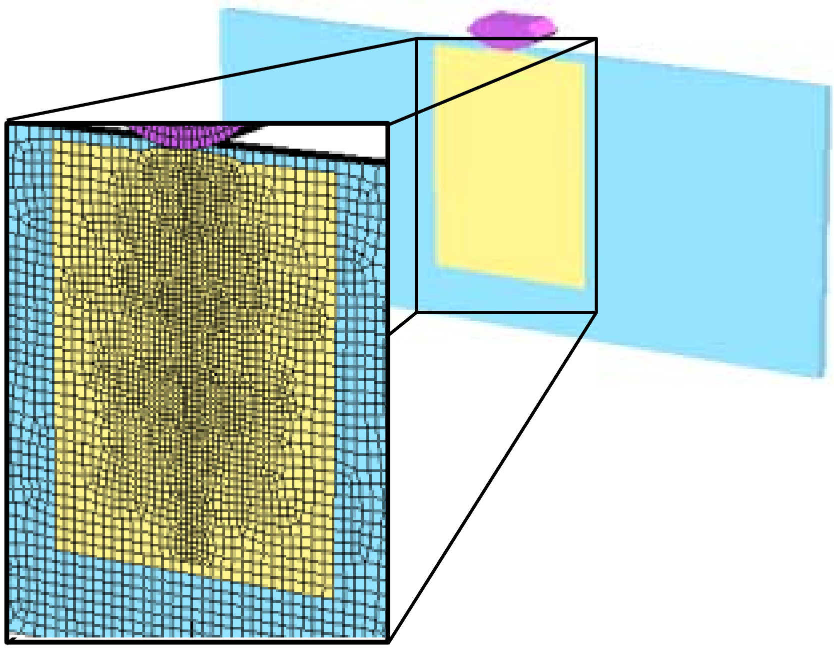
Comparison

	No Fracture		Fracture	
	Memory (Mb)	Time(μs)	Memory (Mb)	Time (μs)
256	0.92	17.1	3.33	60.7
425	1.37	16.5	5.38	54.4
648	1.96	15.5	8.08	53.4
2,800	7.39	14.2	33.8	52.5
8,775	22.1	13.9	105	56.0
20,000	49.5	14.8	239	61.6

Comparison w/Cohesive Model

- Pandolfi A, Guduru PR, Ortiz M, Rosakis AJ. Three dimensional cohesive-element analysis and experiments of dynamic fracture in C300 steel. *Int. J. Sol. Struc.* 2000; 37(27):3733-3760.

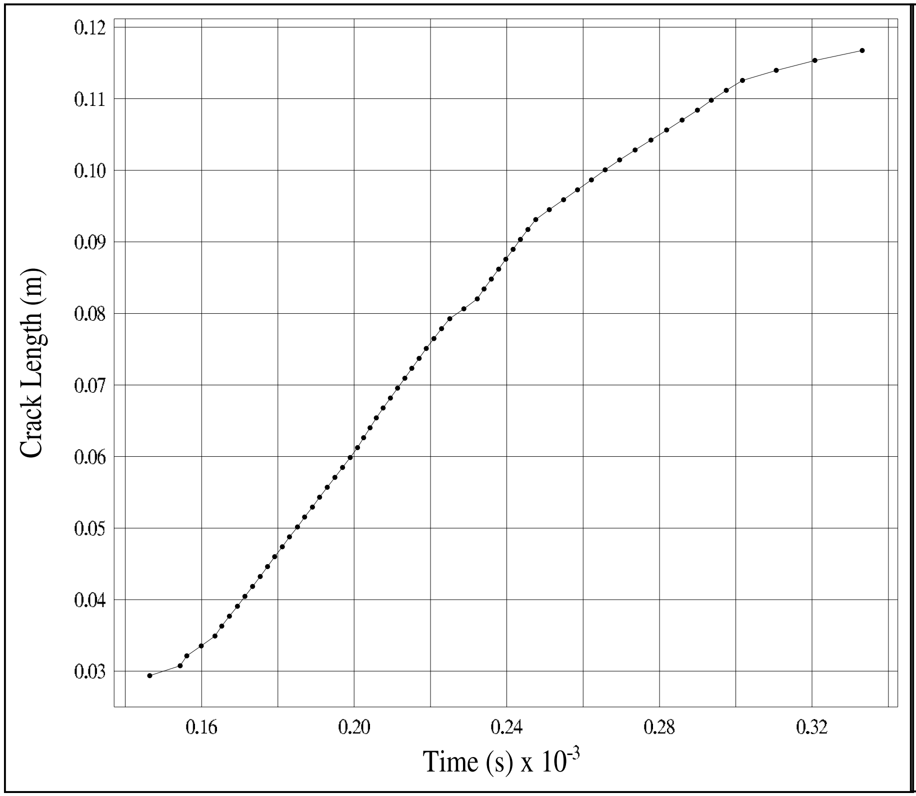




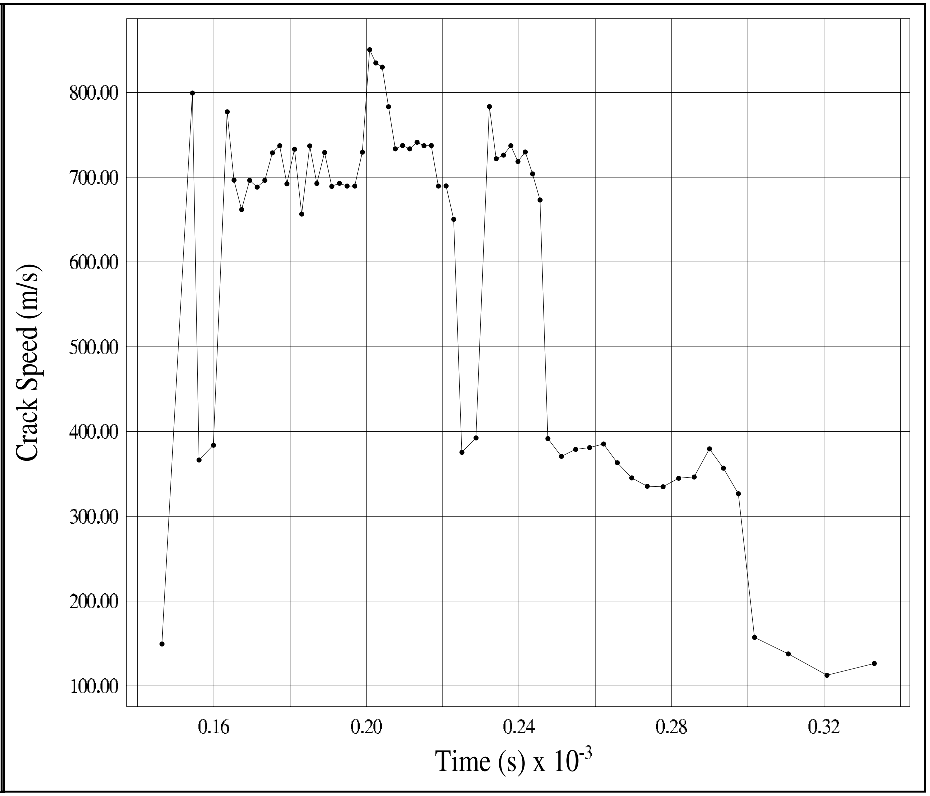
Compare

	Pandolfi, *et al.*	Gerken, *et al.*
Continuum Model	J2 Plasticity, Power Hardening, Rate Dependency, Thermal Softening	Bi-Linear Elastic/Plastic
Element	Quad. Tet.	Linear Brick
Yield Stress	1 GPa	1GPa
Max. Interface Stress	2 GPa	2 GPa
Mesh Size	1.4 mm	1.4 mm
Initiation Time	0.11 ms	0.13 ms
Length after 0.09 ms	0.084 m	0.079 m
Avg. Speed	633 m/s	578 m/s

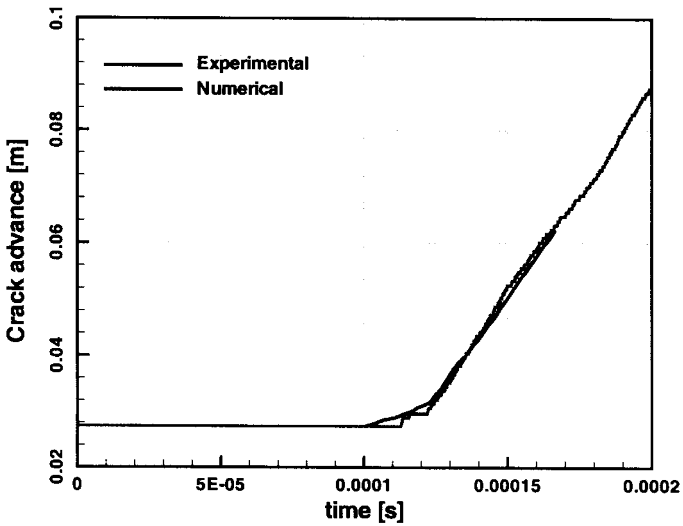
Compare



Crack Length (m)
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.16
0.20
0.24
0.28
0.32
Time (s) x 10^{-3}

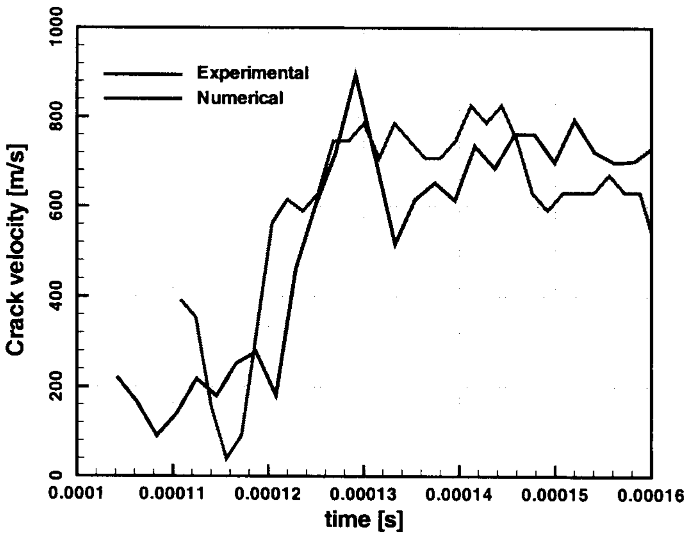


Crack Speed (m/s)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.16
0.20
0.24
0.28
0.32
Time (s) x 10^{-3}



Experimental
Numerical
Crack advance [m]
0.02
0.04
0.06
0.08
0.1
0
5E-05
0.0001
0.00015
0.0002
time [s]

(a)



Experimental
Numerical
Crack velocity [m/s]
0
200
400
600
800
1000
0.0001
0.00011
0.00012
0.00013
0.00014
0.00015
0.00016
time [s]

Conclusions

- Methods for modeling fracture are advancing
- Implementation for analyst's use is needed
- This work provides:
  - Transparent method for geometry evolution
  - Testbed for fracture criteria
- Comparison with standard simulation shows computational cost is not overwhelming
- Comparison with other method shows qualitative agreement